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ABSTRACT

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RESTORING THE INITIAL HEAT-RESISTING PROPERTIES
OF MATERIALS BY INTERMEDIATE HEAT TREATING

I.I. Trunin, Cand. Eng.

Central Scientific-Research Institute of
Technology and Mechanical Engineering

Results are presented of a study of
the degree of damage at various stages
of creep of specimens of a steel of
the austenitic class.

Numerous studies of the mechanism of the plastic
deformation and the fracture of materials under conditions
of creep at high temperatures have shown that the predominant
roles in the phenomenon of stress rupture are played by the
diffusion processes. In several studies, Ref 1 for example,
the reversibility of the stress-rupture process in the early
stages of its development has been shown.

A significant increase in the service life of ma-
terials (Ref 2) has been achieved by an intermediate heat
treatment. In this case it was noted that at relatively
low stresses the intermediate heat treatments could increase
the service life of the material by several times. At the
higher stresses the susceptibility appears to a lesser degree
and the possibility of slowing the stress rupture process
is reduced.

The recovery of the properties after long-term
operation of the material of turbine blades was shown by
Glikman in his study of the variation of the damping de-
crement (Ref 4).

The intermediate heat treatment, in addition to
slowing of the stress-rupture process, can restore the
initial structure and the phase composition, aids in the
equalization of properties between individual grains and
the redistribution of the microstresses with the elimination
of the peaks in the areas of stress concentration. All this
can lead to an increase of the service life of the parts or
to an increase of the working loads for the same duration of
operation.

However the question has still not been resolved of
to what stage the development of the stress-rupture process
is reversible and to what degree we can "heal" the fracture
centers by the intermediate heat treatment. The present
article presents the results of an experimental verification
in laboratory conditions of the possibility of healing damage

accumulated in the material at various stages of the fracturing under creep conditions.

As the object of the study we used the metal of the working section of specimens tested in creep and stress-rupture of several high-temperature steels: the EI-257, EI-1T steels and a nickel alloy.

Table 1 presents the test conditions for these specimens. We see that the test duration varied from several hundred to several thousand hours, i.e. the testing was interrupted at various stages of the stress-rupture testing. The extent of damage was evaluated on the basis of the change of the density of the metal. The magnitude of the density was determined by the method of hydrostatic weighing. One specimen of each pair from the EI-257 steel after the creep test was subjected to heat treatment (heated to 800C, soak for 5 hours, furnace cooled) to heal the accumulated damage. The error in the measurement of the density did not exceed 0.001 which corresponded to 5-10% of the measured values.

Table 1

№ группы (a)	Марка стали (e)	Температура испытания, °С (j)	Напряжение σ, кгс/мм² (k)	Длительность испытания, ч (l)	Число образцов (m)	Примечание (n)
Первая группа (b)	ЭИ-257 (f)	580	24	200	2	—
		580	24	500	2	—
		580	21	1 000	2	—
		580	24	1 500	2	—
		580	24	2 000	2	—
		580	24	2 500	2	—
		580	24	3 500	2	—
Вторая группа (c)	ЭИ-257	580	26	100	8	—
		580	26	300	8	—
		580	26	500	8	—
Третья группа (d)	Никелевый сплав (g)	750	30	140	1	Образец разорвался (o)
		750	25	585	1	То же (p)
	ЭИ-1Т (h)	600	20	1 846	1	..
		600	22	979	1	
		600	24	851	1	
	Сталь 45 (i)	20	—	—	4	Кратковременный разрыв (q)

a - group No; b - first group; c - second group; d - third group; e - steel grade; f - EI-257; g - nickel alloy; h - EI-1T; i - steel; j - test temperature; k - stress in kg/mm²; l - test duration in hours; m - number of specimens; n - remarks; o - specimen failed; p - same; q - short-term tension

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In one group of the studies the accuracy of the determination of the density was increased by testing of parallel samples. In another group an improvement of the reliability of the estimate of the degree of damage was achieved by the use of the Machlin technique, (Ref 1). The exposure of the pores and microcracks obtained under the creep conditions was accomplished by means of active deformation at lower temperatures. For this purpose all the specimens were subjected to a uniform elongation of 10% at normal temperature. Such a deformation should aid in the exposure of the pores and microcracks accumulated under the creep conditions. If the heat treatment had healed over the fracture centers, then during the cold deformation no discontinuities should develop in the metal.

Fig 1 presents a plot of the variation of the density of the metal after creep (curve 1) and after the subsequent heat treatment (curve 2) for the specimens of the first group (σ = 24 kg/mm^2).
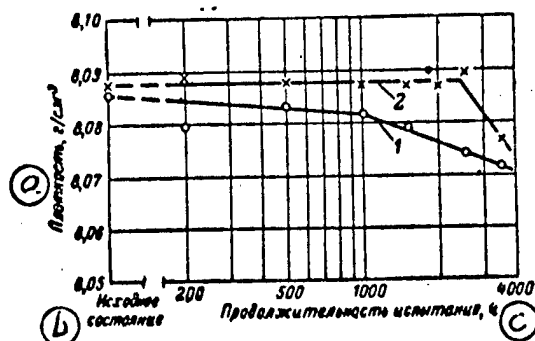

Fig 1. Variation of the density of EI-257 steel
during creep as a function of test duration
Θ = 580C, σ = kg/mm^2

1 - after creep test the specimen was work hardened by 10% elongation in the cold condition; 2 - after creep testing the sample was heat treated by heating to 800C, soak for 5 hours, then work hardened in the cold condition by 10% a - density, g/cm^3; b - initial condition; c - test duration, hours

We note the following from Fig 1. The damage of the metal starts in the first stage of creep; after 200 and 500 hours of testing there is a reduction of the density. With

an increase of the testing time there is a noticeable acceleration of the damage process; after 1000 hours the rate of decrease of the density goes up. The major portion of the defects are subject to healing with heat treatment if the time to failure is not more than half used up, up to 2500 hours the density is practically completely restored; with longer test duration the magnitude of the density increases insignificantly, i.e. only the small failure centers are subject to healing. In the second group the stress rupture test was conducted at a higher stress ($\sigma = 26$ kg/mm^2). Considering the static nature of the stress-rupture test and the associated scatter of the experimental data, we determined the mean time to failure from the results of numerous repeated tests.

After evaluating in this fashion the expected time to failure ($\bar{\theta}_k \approx 500$ hours) we conducted tests using the same conditions in three series with eight samples in each (Table 1). The duration of the testing of the first series was 20% of the mean life: $\theta_1 = 0.2\,\bar{\theta}_k$. In the second series $\theta_2 = 0.6\,\bar{\theta}_k$. The duration of the tests of the third series of samples was equal to the mean life ($\theta_3 = \bar{\theta}_k$), i.e. the failure process reached the final stage.

After the stress rupture tests half of the samples of each series were subjected to heat treatment for the purpose of healing the fracture centers (austenitizing at 1100C, soak for 30 min). In this group the estimate of the damage was made on the basis of the results of the determination of the mechanical properties of the steel at normal temperature. Table 2 presents the results of the test in short-term tension of the samples tested for creep. Table 3 presents analogous results of the test in short-term tension of the samples which were subjected to heat treatment after the creep testing.

We see from the tables that the damage in the creep conditions has the greatest effect on the plasticity characteristics (σ and ψ) and on the true resistance to fracture (S_k). If we judge on the basis of the variation of δ, ψ and S_k then we can note that for a test duration of 300 hours, i.e. about 40-60% of the service life, the healing completely liquidates the creep damage. Increase of the test duration leads to the formation of stable microcracks and the failure process becomes irreversible.

Table 2. Mechanical properties of EI-257 at 20C after stress rupture testing at 580C and 26 kg/mm²

Продолжительность испытания на длит. прочность, (a)	Предел ползучести σ_s, кгс/мм² (b)	Предел прочности $\sigma_в$, кгс/мм² (c)	Истиное нормальное конечное напряжение $S_к$, кгс/мм² (d)	Относительное удлинение δ, % (e)	Относительное сужение ψ, % (f)
100	39.6	63.9	176.8	59.6	69.9
	39.9	62.6	153.5	56.0	65.0
Среднее (g) 300	39.8	62.2	166.2	57.8	67.0
	41.9	64.4	172.2	59.6	72.1
	39.9	61.7	132.1	36.8	51.2
Среднее 500	40.9	63.0	152.2	48.2	61.7
	44.3	68.8	98.5	25.2	31.2
	44.6	69.5	113.4	32.4	40.9
Среднее	41.4	69.2	106.0	28.8	36.0

a - duration of stress rupture test; b - creep limit; c - ultimate strength; d - true normal final stress; e - relative elongation; f - relative reduction; g - average

Table 3. Mechanical properties of EI-257 steel at 20C after stress rupture testing at 580C and 26 kg/mm² and a restoring heat treatment at 1100C for 30 minutes

Продолжительность испытания на длительную прочность, (a)	Предел текучести σ_s, кгс/мм² (b)	Предел прочности $\sigma_в$, кгс/мм² (c)	Истиное нормальное конечное напряжение $S_к$, кгс/мм² (d)	Относительное удлинение δ, % (e)	Относительное сужение ψ, % (f)
100	20.8	54.3	193.3	74.4	76.1
	20.5	55.4	194.7	76.4	78.6
Среднее (g) 300	20.6	54.8	194.0	75.4	77.4
	20.3	55.3	201.0	82.4	79.8
	19.5	55.2	199.1	71.6	76.8
	19.8	53.8	185.8	79.2	77.1
Среднее 500	19.9	54.8	192.5	77.7	77.9
	18.8	54.8	151.6	70.8	66.5
	20.1	52.4	117.0	57.2	56.1
Среднее	19.5	53.6	134.3	64.0	61.3

a - duration of stress rupture test; b - creep limit; c - ultimate strength; d - true normal final stress; e - relative elongation; f - relative reduction; g - average

Thus both groups of tests indicated that the intermediate heat treatment permits the liquidation of the major portion of the failure centers if not more than half of the creep service life has been used up.

In the third group we used as test specimens the remains of the samples which had been tested to failure in creep or in short-term tension. One half of these samples were subjected to healing by heat treatment. The estimate of the degree of damage was made by the measurement of the density. The density of the metal of each half of the sample was determined from the results of triple measurements. After the first measurement, a portion of the metal was removed by a cutter (lathe) from the end opposite the location of the failure. Then the density of the reduced metal sample was measured. This operation was repeated several times. The first measurement essentially determined the density of the portion of the metal of the working part of the samples located far from the fracture. As the samples were reduced in size by removal of metal from one end, the tested portion approached the fracture location, the zone of maximum damage. The final measurement of the density determined the density of a small volume of metal in which the damage is at a maximum. Thus we established the variation of the density as a function of the metal volume, i.e. as a function of the degree of damage in the stress rupture test.
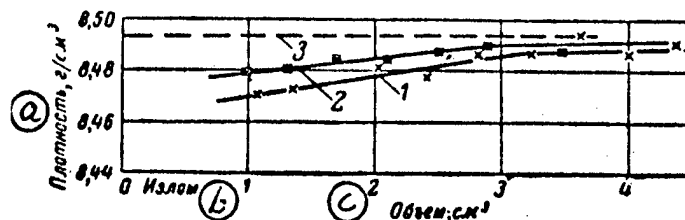

Fig 2. Variation of the density of the forging alloy TsZH-6 after stress rupture ($\theta = 750C$, $\sigma = 30$ kg/mm^2, $\theta_k = 140$ hours, $\varepsilon_k = 9.0\%$, $\psi = 19.0\%$)

1 - after testing; 2 - after testing and heat treatment at 1200C for 1.5 hours, annealed at 750C for 20 hours; 3 - initial condition; a - density in g/cm^3; b - fracture; c - volume, cm^{-3}
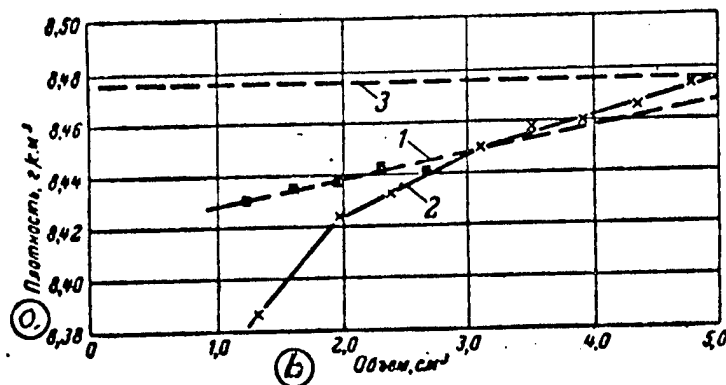
Fig 3. Variation of the density of the forged
alloy TsZh-6 after stress rupture ($\theta = 750C$,
$\sigma = 25$ kg/mm^2, $\bar{\theta}_k = 585$ hours, $\varepsilon_k = 9.2\%$,
$\psi_k = 22.8\%$)

1 - after testing; 2 - after testing and heat treatment at
1200C for 1.5 hours, anneal at 750C for 20 hours; 3 - initial
condition; a - density, g/cm^3, b - volume, cm^{-3}

        Figs 2 and 3 present plots of the variation of the
density of two samples of the nickel alloy. Fig 4 shows
the variation of the density in creep conditions of one of
the samples of the grade EI-1T steel (Table 1). First of
all we should note that in both cases plastic deformations
of similar magnitude, both overall (ε_k) and local (ψ_k)
preceded the fracture.
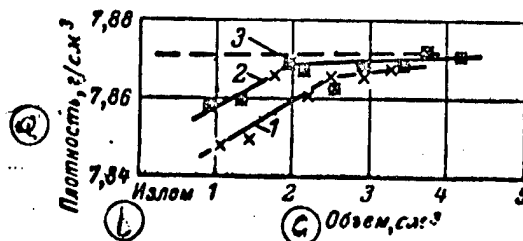

Fig 4. Variation of the density of the EI-1T alloy
after stress rupture ($\theta = 600C$, $\sigma = 20$ kg/mm^2,
$\theta_k = 1846$ hours)

1 - after testing; 2 - after testing and heat treatment at
1040-1100C for 30 min, anneal at 800C for 10 hours; 3 -
initial condition; a - density, g/cm^3; b - fracture; c -
volume

Analysis of the results of the study of the accumulation of defects in the zones adjacent to the fracture showed that during the first stage of creep the initiation and the growth of the defects takes place throughout the entire volume of the working portion of the samples. However in this stage the dimensions of the defects are small and they are subject to healing; the magnitude of the density reaches the initial level (Figs 2 and 4).

Increase of the time up to the point of failure leads to a noticeable localization of the failure processes in the volume of the working portion of the samples. Right in the region of the fracture there is noted a significant acceleration of the decrease of the density (Figs 3 and 4). In this zone there probably occurs growth of the defects, most of which attain a critical dimension and their healing becomes impossible; after the restoring heat treatment the density of the metal is restored only by 50%. Judging from the plots of Figs 3 and 4 the healing is effective only prior to the localization of the failure process.

Some additional information on the kinetics of the stress rupture is given by a comparison of the results of the study of the investigation of the samples of the first (Fig 1) and the third (Figs 3 and 4) groups. In the first group of the tests during the creep process there was no localization of the plastic deformation along the length of the working section noted in any of the samples (absence of a neck) and judging by the initial curves for the stress-rupture (Fig 5) the third stage of accelerated creep did not appear.

If we compare these data with the results of the healing (Fig 1) then we can note that a large number of the defects reach the critical dimension prior to the onset of the third stage of creep in the absence of the localization of the development of the plastic deformation. Actually, after 3500 hours of testing (Fig 1) there is observed a slight increase of the density after the heat treatment, i.e. a significant number of the defects exceeded the critical dimension.

It appeared of interest to study the possibility of healing the failure centers formed during the active deformation under conditions of normal temperatures, i.e. when the diffusion processes do not play any role in the initiation and the growth of the fracture centers. To answer this question we carried out similar investigations on the remains of the samples of the steel 45 after short-term tension fracture at normal temperature.
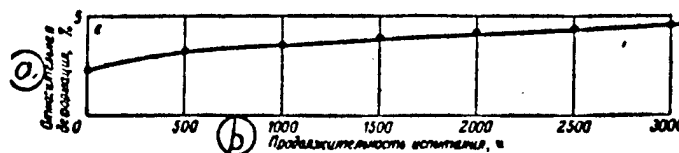
Fig 5. EI-257 steel. Initial stress rupture
curve at $\theta = 580C$, $\sigma = 24$ kg/mm^2. a - relative
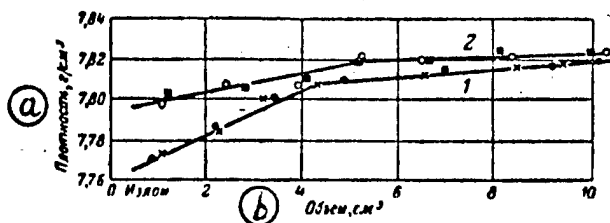deformation; b - test duration, hours

Fig 6. Variation of the density of steel 45
after short-term tension fracture
1 - after testing; 2 - after testing and heat
treatment at 800C for 5 hours
a - density, g/cm^3; b - volume, cm ^{3}

Fig 6 is a plot of the tests of the two samples.
The results of the measurement of the density of the metal
of both samples practically coincided and this permitted
drawing single curves for the variation of the density prior
to and after heat treatment. Comparison of the graphs of
Figs 4 and 6 shows that the variation of the density, and
consequently the development of the fracture centers along
the volume of the working portion during active deformation,
does not differ in nature from the development of the defects
in the samples during the creep testing. On the basis of
these results we can draw the conclusion that defects formed
by both the diffusion and the shear formation mechanisms
are subject to healing.
The results of the study made permit the proposing
of the hypothesis of the possibility of increasing the
service life of components of an electric power station
fabricated from heat-resistant materials by performing inter-
mediate heat treatments after intervals of time amounting
to 25-30% of the design service life. This recommendation
must be checked under industrial conditions. In practice
the most convenient items for testing are the fittings,

whose service life could be extended significantly by the use of intermediate treatment.

REFERENCES

1. Chen C.W., Machlin E.S., J. of Metals, Vol 9, No 7, (Section II), 1957
2. Tum A., Rikhard K., article in the collection Studies of Heat-Resistant Steels and Alloys, Metallurgizdat, 1960
3. Glikman L.A., Grinberg M.I., ZhTF (Journal of Technical Physics), Vol XVI, No 9, 1946
4. Trunin I.I., Mirkin I.L., Metallovedeniye i obrabotka metallov, (Metal Science and the Treatment of Metals), No 11, 1958